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APT USERS' GUIDE

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Errata Sheet on AFCRL-63-655 (ARA-T-(219-1) June 1963

Page 6 Should read - last line.

- 12th orbit following reference orbit. (instead of 8th)

Page 21 Should read - first line under $\begin{array}{c}\text{TIME}\\(\text{Z})\end{array}$.

13 55 48 (instead of 13 55 12)

FOREWORD

The work resulting in this report was performed by Allied Research Associates, Inc., Concord, Massachusetts, and was sponsored by the Air Force Cambridge Research Laboratories, Office of Aerospace Research, under Contract No. AF 19(628)-2471, Project No. 6698, Task No. 669802.

Supporting background information concerning the Nimbus APT subsystem was provided to the author by the U. S. Weather Bureau, National Aeronautics and Space Administration and Air Weather Service. Discussions and evaluations of operational techniques with personnel of the above agencies led to improvements which were subsequently incorporated in this report.

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SECTION I
INTRODUCTION

This report is intended as a guide to data handling techniques for the Nimbus Automatic Picture Taking (APT) sub-system. No attempt is made to present a sophisticated treatment of all facets of rectification or geographic referencing. It is anticipated that operating personnel will attend a training course on this subject in which theory and detailed practice will be laid out.

Although the APT sub-system was originally intended to be flown aboard the Nimbus satellite, an experimental TIROS APT sub-system may preceed the Nimbus flight. An appendix covers additional procedures required to cope with the TIROS attitude problem.

This manual should be used in conjunction with materials specifically developed for the APT sub-system, especially the "APT Tracking Board".

SECTION II
AUTOMATIC PICTURE TAKING SUB-SYSTEM

2.1 General

The Automatic Picture Taking (APT) sub-system was conceived to permit meteorologists to obtain promptly satellite cloud pictures in their immediate area of interest. Experience with the TIROS satellite system has indicated the value of permitting the meteorological analyst to examine the actual satellite picture. Direct satellite readout avoids the problems of re-transmission of pictures, elaborate communication equipment, degradation of pictorial information content and time consuming communication networks which diminish the value of perishable information. The APT sub-system represents an initial attempt to overcome most of the above problems.

2.2 Nimbus APT Sub-System

The Nimbus satellite contains a camera and television system arranged to take pictures at a nominal 208 second interval after the initial picture. Pictures will be taken only over the sunlit portion of the earth. This will correspond to the south to north leg of the orbit, according to present plans.

A Tegea lens (f:1.8, 5.7 mm focal length) with a 108° diagonal field of view is positioned in front of a one inch square vidicon. Only the central portion of the vidicon (.44 x .44 inches) is scanned. Picture scanning is completed in approximately 200 seconds. The scanning rate is 4 lines per second.

During picture scanning, a continuous broadcast of the scanned pictorial information is made from the satellite. This continuous broadcast is available to any interested consumer, within acquisition range, who has the appropriate receiving antenna and equipment.

Terminal ground equipment is a special facsimile machine capable of reconstructing the signals received from the local acquisition antenna. The picture appears in an 8 x 8 inch format. Ten levels of contrast, from black to white inclusive, are available on the picture. A matrix of 25 fiducial marks appears, the central cross indicating the approximate principal point of the picture. The principal point of the picture is the intersection of the optical axis of the lens with the picture plane.

The Nimbus satellite system is designed to be launched into a circular retrograde orbit with an inclination of about 81°. The satellite will be earth oriented, i.e., always "looking" toward the center of the earth. Therefore, the geographic location of the principal point of the picture should be at or near the sub-point of the satellite at the instant the satellite camera shutter is opened.

SECTION III
DATA DISSEMINATION

3.1 Introduction

Orbital information required by the APT acquisition teams will be provided routinely in two forms: a daily message via teletype circuits and a weekly message to be disseminated by some other means. During all normal modes of operation, the daily message will be used exclusively. The weekly message is intended for use when daily messages are unavailable to the user.

3.2 Daily Message

The Nimbus daily message is divided into four basic sections. Part one contains the following information:

a) Ascending node data for a reference orbit, i.e., day, time, and longitude.
b) Nodal period (time interval between successive ascending nodes).
c) Nodal longitude increment (degrees of longitude between successive ascending nodes).

The above information is repeated for every fourth orbit following the reference orbit for the day.

Part two contains pertinent information concerning the spatial location of the satellite during an orbital period. Satellite sub-points (latitude and longitude) and heights are given at two minute intervals <u>after</u> ascending node for the sunlit segment of the orbit. Part three provides similar information at two minute intervals <u>before</u> ascending node for the sunlit segment of the orbit.

Part four of the daily message is reserved for "remarks" pertinent to operational aspects of the Nimbus APT system.

A sample layout of the daily message is shown in Figure 1. Tables 1 and 2 present detailed explanations of the symbols used in Figure 1.

3.3 Weekly Message

The weekly message is to be used for back-up purposes in the event that the daily messages are not received for a relatively extended period. One month of predicted data will be present in the weekly message. Data contained in this message will be essentially the same but more elaborate, as that in the daily message.

FIGURE 1

NIMBUS APT ALERT AND EPHEMERIS PREDICT

T BUS 2 KWBC_________________Z

APT PREDICT

MMDDNN

PART I

$ON_rN_rN_rN_r$ OYYGG Oggss $QL_oL_ol_ol_o$ Tmmss $LL_oL_ol_ol_o$

$N_4N_4N_4N_4G_4$ $G_4g_4g_4s_4s_4$ $Q_4L_oL_ol_ol_o$

$N_8N_8N_8N_8G_8$ $G_8g_8g_8s_8s_8$ $Q_8L_oL_ol_ol_o$

$N_{12}N_{12}N_{12}N_{12}G_{12}$ $G_{12}g_{12}g_{12}s_{12}s_{12}$ $Q_{12}L_oL_ol_ol_o$

PART II

02ZZQ $L_aL_al_aL_oL_ol_o$ 04ZZQ $L_aL_al_aL_oL_ol_o$

06ZZQ $L_aL_al_aL_oL_ol_o$ 08ZZQ $L_aL_al_aL_oL_ol_o$

10ZZQ $L_aL_al_aL_oL_ol_o$ ---etc.

PART III

02ZZQ $L_aL_al_aL_oL_ol_o$ 04ZZQ $L_aL_al_aL_oL_ol_o$

06ZZQ $L_aL_al_aL_oL_ol_o$ 08ZZQ $L_aL_al_aL_oL_ol_o$

10ZZQ $L_aL_al_aL_oL_ol_o$ ---etc.

PART IV

TABLE I

EXPLANATION OF CODE SYMBOLS; PART I

TBUS 2	- NIMBUS APT BULLETIN originating in the United States
KWBC	- Traffic entered at Washington, D. C.
APT PREDICT	- Identifies message content.
MMDDNN	- Message serial number MM - month DD - day NN - number of Nimbus to which predict applies
PART I	- Equator crossing predicts follow.
$ON_rN_rN_rN_r$ OYYGG Oggss	
O	- Indicator, reference orbit equator crossing info follows. (NOTE: Information in PARTS II and III applies directly to the reference orbit.)
$N_rN_rN_rN_r$	- Number of reference orbit
YYGGggss	- Day, hour, minute, second (GMT) on which satellite crosses the equator northbound on reference orbit $N_rN_rN_rN_r$.
$QL_oL_ol_ol_o$	- Octant and longitude in degrees and hundredths at which satellite crosses the equator north-bound on reference orbit $N_rN_rN_rN_r$.
T	- Indicator, nodal period follows.
mmss	- Nodal period, minutes and seconds between consecutive equator crossings.
L	- Indicator, nodal longitude increment follows.
$L_oL_ol_ol_o$	- Degrees and hundredths of longitude degrees between consecutive equator crossings.
$N_4N_4N_4N_4$	- Number of the fourth orbit following the reference orbit.
$G_4G_4g_4g_4s_4s_4$	- Hour, minute, second at which satellite crosses the equator northbound on orbit N_4.
$Q_4L_oL_ol_o$	- Octant and longitude in degrees and hundreths at which satellite crosses equator northbound on Orbit N_4.
$N_8N_8N_8N_8$	- 8th orbit following reference orbit.
$N_{12}N_{12}N_{12}N_{12}$	- 8th orbit following reference orbit.

TABLE 2

EXPLANATION OF CODE SYMBOLS; PART II

PART II	- Satellite altitude and sub-point coordinates at 2 minute intervals -- after time of equator crossing follows.
02ZZQ	
02	- Information pertinent to minute 2 after equator crossing follows.
ZZ	- Satellite altitude in tens of kilometers.
Q	- Octant of globe
$L_aL_al_a$	- Latitude of satellite sub-point in degrees and tenths of degrees at minute 2 after equator crossing.
$L_oL_ol_o$	- Longitude of satellite sub-point in degrees and tenths of degrees at minute 2 after equator crossing.

(This information is repeated at 2 minute intervals over the sunlit portion of the orbit north of the equator.)

PART III	- Satellite altitude and subpoint coordinates at 2 minute intervals prior to time of equator crossing follows.
02ZZQ	
02	- Information pertinent to minute 2 <u>before</u> equator crossing follows.
ZZ	- Satellite altitude in tens of kilometers
Q	- Octant of the globe.
$L_aL_al_a$	- Latitude of satellite subpoint in degrees and tenths of degrees at minute 2 before equator crossing.
$L_oL_ol_o$	- Longitude of satellite subpoint in degrees and tenths of degrees at minute 2 before equator crossing.

(This information is repeated at 2 minute intervals over the sunlit portion of the orbit south of the equator.)

PART IV	- Remarks.

SECTION IV
TRACKING

4.1 Introduction

A directional antenna is used to receive the APT signals. The antenna must be roughly pointed at the satellite for maximum signal (high signal to noise ratio) strength. The procedure for keeping the antenna pointed at the satellite as it moves is referred to as "tracking".

To track the satellite properly its location must be known relative to the location of the tracking antenna. The method of presenting tracking data is in terms of satellite azimuth and elevation from the antenna location.

The remainder of this section will describe the technique for determining which satellite orbits can be acquired and the procedure for locally preparing tracking data.

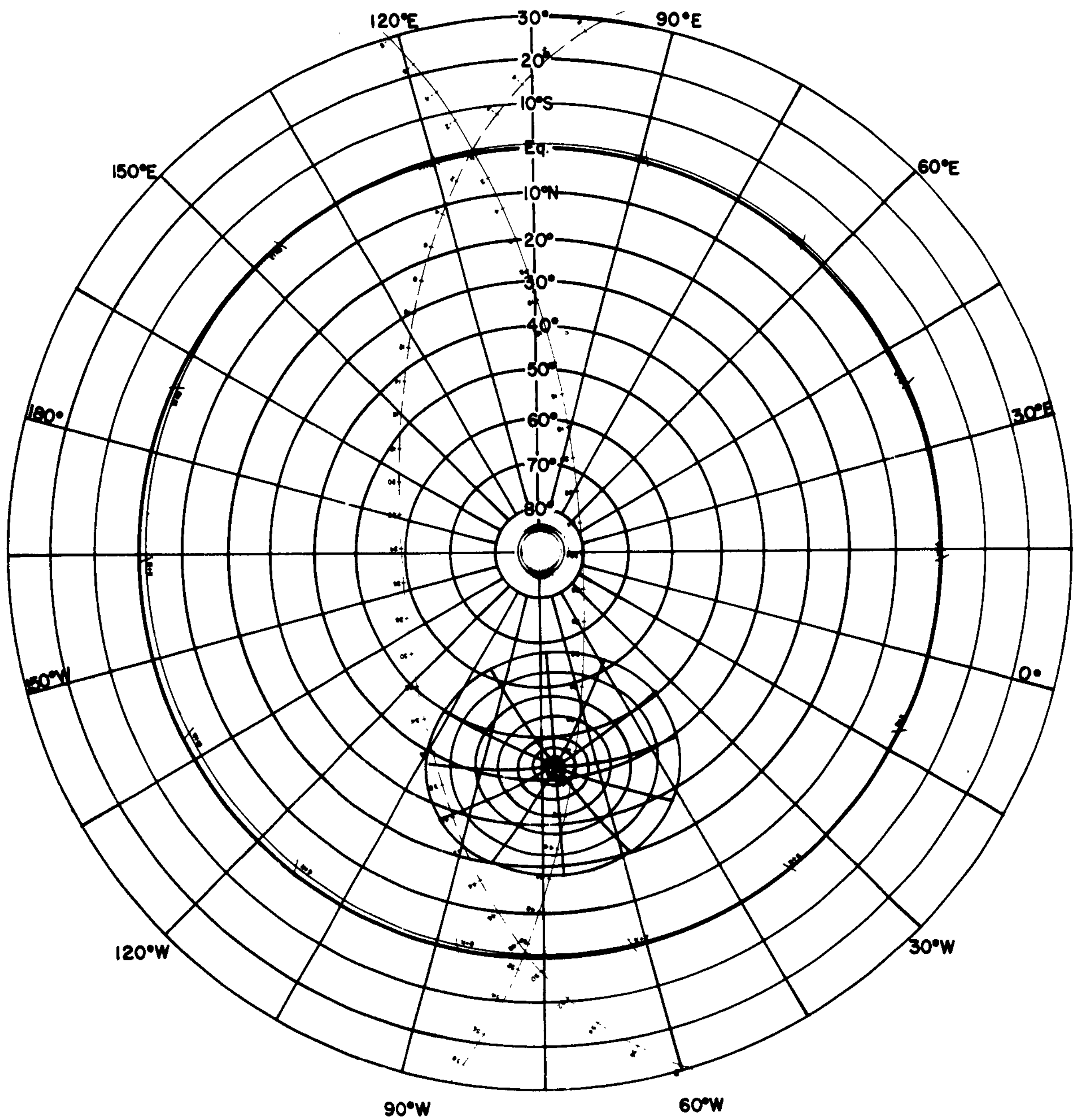
4.2 APT Tracking Board

The APT Tracking board is a circular slide rule device designed to assist the operator in locally determining tracking data. Figure 2 is a simplified version of the tracking board, which contains an azimuth-equidistant projection of 12 inch radius printed on a 30 x 30 inch base. For visual clarity, only a portion of the lines appearing on the operational board are reproduced. The following text describes the operational model rather than the simplified version of Figure 2.

The base-board contains an azimuth-equidistant projection of a spherical earth from the pole through the equator to 30^{o} latitude of the opposite hemisphere. It may be observed that the above projection can be used for both the northern and southern hemispheres since the projections are identical (symmetrical) from each pole.

Radials from the poles represent one degree longitude markers, every fifth radial being accentuated. Longitudes are labeled at the radial extremities. Concentric circles on this projection represent latitudes. For convenience, the latitude circle identifiers appear on a seperate arm which is pivoted about the pole. The equatorial latitude (0^{o}) is represented by a heavier circle since it will be used often for reference purposes.

APT TRACKING BOARD
MODEL



Superimposed on the azimuth-equidistant chart is a tracking diagram centered at the latitude-longitude of the local tracking antenna. This diagram will be used to determine tracking data.

A transparent overlay is provided which contains the projection on earth of the orbital path (sub-point track) of the satellite. Hatch marks on the sub-point track represent two minute time intervals referenced to the equator (ascending node of the satellite). We assume here that the azimuth-equidistant projection is being used for the northern hemisphere. Note that the equatorial latitude circle on the transparent overlay (see board) contains arrows at about 25.3° intervals of longitude. These arrows represent ascending nodes of successive Nimbus orbits referenced to the sample sub-point track (noted as "N"). Orbit numbers are arbitrarily incremented by one with successive northbound equator crossings of the satellite. Thus, if the sample orbit (N) is designated orbit number 53 (N = 53), that part of the sample orbit which appears south of the equatorial circle is N-1 or orbit number 52.

It should be pointed out that the data which appear in graphical form on the transparent overlay are nominal values based on pre-launch calculations. Post-launch data received from the daily message will contain more refined data. These data may be used to plot an up-dated sub-point track and ascending node longitude increments on the blank overlays which are supplied with the tracking board.

4.3 Tracking Diagram

Determination of azimuth and elevation tracking data is a function of satellite height and the geographic latitude of the local tracking antenna. A spherical earth is assumed. Most tracking diagrams are of the azimuth-elevation type; however, such a diagram must assume a specific constant satellite height (circular orbit).

A universal tracking diagram can be drawn if one replaces the elevation with great circle arc length curves having a common origin at the geographic location of the antenna. Azimuth-great circle arc length tracking diagrams are a function of geographic latitude only. Such a diagram is shown on the APT tracking board.

The slightly curved lines radiating from the center of the tracking diagram are segments of great circles projected onto the azimuth-equidistant polar chart. Direction of the great circles represent the tracking azimuth. Distance along the great circles measured in degrees of arc length can be converted to elevation angles for specified satellite heights. Tables 3, 4, 5 and 6 contain satellite elevation angles as a function of great circle arc length (degrees) and height. The tracking diagram contains isopleths of two degrees great circle arc length. These isopleths appear as closed curves (nearly elliptic) with their origin at the center of the diagram. Identifying labels for the isopleths have been intentionally omitted. The user is requested to label these isopleths in the direction and location which is most convenient to him. The outer isopleth represents 36° of great circle arc length from the origin.

To obtain tracking data, the user will read values of azimuth and great circle arc length. Arc length will then be converted to elevation angle by noting the satellite height (from the daily message) at the desired data point.*

For convenience, Table 7 lists the great circle arc length for zero degree elevation angles as a function of satellite height.

4.4 Tracking Range Limits

4.4.1 Theoretical

For simplification, one may assume that signals emitted from the satellite radiate in straight lines. Thus, any signal from the satellite which can be picked up by the ground receiving antenna must be within line-of-sight of the antenna. Therefore, the initial signal which can be received by the antenna is when the satellite appears on the local horizon, i.e., the antenna elevation is zero. Similarly, the last signal received at the antenna is when the satellite disappears over the local horizon, i.e., the antenna elevation returns to zero.

The local horizon for each acquisition station is represented by a 0° elevation circle on an azimuth-elevation diagram. This 0° elevation circle is used to determine which orbits can be acquired by the local APT ground station.

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*After the satellite is launched into orbit and the satellite height is well established, it is possible to assign elevation angle values to the two degree incremented great circle isopleths on the tracking diagram. This procedure is permissible only if the satellite orbit is very nearly circular.

TABLE 3

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)					HEIGHT (NAUT. MI.)			
	200	225	250	275	300	325	350	375	400
	HEIGHT RANGE (KILOMETERS)					HEIGHT RANGE (KILOMETERS)			
	348 /393	394 /439	440 /486	487 /532	533 /578	579 /625	626 /671	672 /717	718 /764
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	71.5	73.3	74.8	76.0	77.1	78.0	78.7	79.5	80.0
2.	57.9	60.8	63.2	65.1	66.9	68.3	69.6	70.8	71.8
3.	46.2	49.4	52.2	54.7	56.9	58.8	60.5	62.0	63.4
4.	37.3	40.6	43.5	46.1	48.4	50.6	52.5	54.3	55.9
5.	30.7	33.7	36.5	39.1	41.5	43.7	45.7	47.6	49.3
6.	25.5	28.3	31.0	33.4	35.8	37.9	39.9	41.8	43.6
7.	21.4	24.0	26.4	28.8	31.0	33.1	35.0	36.9	38.6
8.	18.1	20.5	22.8	24.9	27.0	28.9	30.8	32.6	34.3
9.	15.3	17.5	19.6	21.6	23.5	25.4	27.2	28.9	30.5
10.	12.9	15.0	16.9	18.8	20.6	22.3	24.0	25.7	27.2
11.	10.9	12.7	14.5	16.3	18.0	19.6	21.2	22.8	24.3
12.	9.1	10.8	12.5	14.1	15.7	17.3	18.8	20.2	21.7
13.	7.4	9.0	10.6	12.2	13.7	15.1	16.6	18.0	19.3
14.	6.0	7.5	8.9	10.4	11.8	13.2	14.5	15.9	17.1
15.	4.6	6.0	7.4	8.8	10.1	11.4	12.7	14.0	15.2
16.	3.4	4.7	6.0	7.3	8.6	9.8	11.0	12.2	13.4
17.	2.2	3.5	4.7	5.9	7.1	8.3	9.5	10.6	11.7
18.	1.1	2.3	3.5	4.6	5.8	6.9	8.0	9.1	10.1
19.	.1	1.2	2.3	3.4	4.5	5.6	6.6	7.7	8.7
20.	*	.2	1.2	2.3	3.3	4.4	5.4	6.3	7.3
21.	*	*	.2	1.2	2.2	3.2	4.1	5.1	6.0
22.	*	*	*	.2	1.1	2.1	3.0	3.9	4.8
23.	*	*	*	*	.1	1.0	1.9	2.7	3.6
24.	*	*	*	*	*	*	.8	1.7	2.5
25.	*	*	*	*	*	*	*	.6	1.4
26.	*	*	*	*	*	*	*	*	.4

TABLE 4

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)								
	400	425	450	475	500	525	550	575	600
	HEIGHT RANGE (KILOMETERS)								
	718 /764	765 /810	811 /856	857 /903	904 /949	950 /995	996 /1042	1043 /1088	1089 /1134
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	80.0	80.5	81.0	81.4	81.8	82.1	82.5	82.7	83.0
2.	71.8	72.7	73.5	74.2	74.9	75.5	76.0	76.5	77.0
3.	63.4	64.6	65.7	66.8	67.7	68.5	69.3	70.0	70.7
4.	55.9	57.3	58.7	59.9	61.0	62.0	63.0	63.9	64.7
5.	49.3	50.9	52.3	53.7	54.9	56.1	57.2	58.2	59.1
6.	43.6	45.2	46.7	48.1	49.5	50.7	51.9	53.0	54.0
7.	38.6	40.2	41.8	43.2	44.6	45.9	47.1	48.2	49.4
8.	34.3	35.9	37.4	38.9	40.3	41.6	42.8	44.0	45.1
9.	30.5	32.1	33.6	35.0	36.3	37.6	38.9	40.0	41.2
10.	27.2	28.7	30.1	31.5	32.8	34.1	35.3	36.5	37.6
11.	24.3	25.7	27.1	28.4	29.7	30.9	32.1	33.3	34.4
12.	21.7	23.0	24.3	25.6	26.9	28.1	29.2	30.4	31.4
13.	19.3	20.6	21.9	23.1	24.3	25.5	26.6	27.6	28.7
14.	17.1	18.4	19.6	20.8	21.9	23.0	24.1	25.2	26.2
15.	15.2	16.4	17.5	18.7	19.8	20.8	21.9	22.9	23.9
16.	13.4	14.5	15.6	16.7	17.8	18.8	19.8	20.8	21.7
17.	11.7	12.8	13.8	14.9	15.9	16.9	17.9	18.8	19.7
18.	10.1	11.2	12.2	13.2	14.2	15.1	16.1	17.0	17.9
19.	8.7	9.7	10.7	11.6	12.6	13.5	14.4	15.3	16.1
20.	7.3	8.3	9.2	10.1	11.0	11.9	12.8	13.6	14.5
21.	6.0	6.9	7.8	8.7	9.6	10.4	11.3	12.1	12.9
22.	4.8	5.7	6.5	7.4	8.2	9.0	9.8	10.6	11.4
23.	3.6	4.5	5.3	6.1	6.9	7.7	8.5	9.3	10.0
24.	2.5	3.3	4.1	4.9	5.7	6.4	7.2	7.9	8.7
25.	1.4	2.2	3.0	3.7	4.5	5.2	6.0	6.7	7.4
26.	.4	1.1	1.9	2.6	3.3	4.1	4.8	5.5	6.2
27.	*	.1	.8	1.5	2.3	2.9	3.6	4.3	5.0
28.	*	*	*	.5	1.2	1.9	2.5	3.2	3.8
29.	*	*	*	*	.2	.8	1.5	2.1	2.7
30.	*	*	*	*	*	*	.4	1.1	1.7

TABLE 5

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDF

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.)					HEIGHT (NAUT. MI.)			
	600	625	650	675	700	725	750	775	800
	HEIGHT RANGE (KILOMETERS)					HEIGHT RANGE (KILOMETERS)			
	1089 /1134	1135 /1181	1182 /1227	1228 /1273	1274 /1320	1321 /1366	1367 /1413	1414 /1459	1460 /1505
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	83.0	83.2	83.5	83.7	83.8	84.C	84.2	84.3	84.5
2.	77.0	77.4	77.8	78.2	78.6	78.9	79.2	79.4	79.7
3.	70.7	71.3	71.9	72.4	72.9	73.4	73.8	74.2	74.6
4.	64.7	65.5	66.2	66.9	67.5	68.1	68.6	69.1	69.7
5.	59.1	60.0	60.9	61.7	62.4	63.1	63.7	64.3	64.9
6.	54.0	55.0	55.9	56.8	57.6	58.3	59.1	59.8	60.4
7.	49.4	50.4	51.3	52.3	53.1	53.9	54.8	55.5	56.2
8.	45.1	46.1	47.1	48.1	49.0	49.9	50.7	51.5	52.3
9.	41.2	42.2	43.3	44.2	45.2	46.1	46.9	47.7	48.5
10.	37.6	38.7	39.7	40.7	41.7	42.6	43.4	44.3	45.1
11.	34.4	35.5	36.5	37.5	38.4	39.3	40.2	41.0	41.8
12.	31.4	32.5	33.5	34.4	35.4	36.3	37.1	38.0	38.8
13.	28.7	29.7	30.7	31.7	32.6	33.5	34.3	35.2	36.0
14.	26.2	27.2	28.2	29.1	30.0	30.9	31.8	32.6	33.4
15.	23.9	24.8	25.8	26.7	27.6	28.5	29.3	30.1	30.9
16.	21.7	22.7	23.6	24.5	25.4	26.2	27.0	27.8	28.6
17.	19.7	20.6	21.5	22.4	23.2	24.1	24.9	25.7	26.4
18.	17.9	18.8	19.6	20.5	21.3	22.1	22.8	23.6	24.4
19.	16.1	17.0	17.8	18.6	19.4	20.2	21.0	21.7	22.4
20.	14.5	15.3	16.1	16.9	17.7	18.4	19.2	19.9	20.6
21.	12.9	13.7	14.5	15.2	16.0	16.7	17.4	18.2	18.8
22.	11.4	12.2	13.0	13.7	14.4	15.1	15.8	16.5	17.2
23.	10.0	10.8	11.5	12.2	12.9	13.6	14.3	15.0	15.6
24.	8.7	9.4	10.1	10.8	11.5	12.2	12.8	13.5	14.1
25.	7.4	8.1	8.8	9.4	10.1	10.8	11.4	12.0	12.7
26.	6.2	6.8	7.5	8.2	8.8	9.4	10.1	10.7	11.3
27.	5.0	5.6	6.3	6.9	7.5	8.2	8.8	9.4	10.0
28.	3.8	4.5	5.1	5.7	6.3	6.9	7.5	8.1	8.7
29.	2.7	3.3	4.0	4.6	5.1	5.7	6.3	6.9	7.4
30.	1.7	2.3	2.8	3.4	4.0	4.6	5.1	5.7	6.2
31.	.6	1.2	1.8	2.3	2.9	3.5	4.0	4.5	5.1
32.	*	.2	.7	1.3	1.8	2.4	2.9	3.4	4.0
33.	*	*	*	.3	.8	1.3	1.9	2.4	2.9
34.	*	*	*	*	*	.3	.8	1.3	1.8
35.	*	*	*	*	*	*	*	.3	.8

TABLE 6

ELEVATION ANGLE AS FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

GREAT CIRCLE ARC LENGTH	HEIGHT (NAUT. MI.) 800	825	850	875	900	HEIGHT (NAUT. MI.) 925	950	975	1000
	HEIGHT RANGE (KILOMETERS) 1460 /1505	1506 /1551	1552 /1598	1599 /1644	1645 /1690	HEIGHT RANGE (KILOMETERS) 1691 /1736	1737 /1783	1784 /1829	1830 /1875
0.	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
1.	84.5	84.6	84.8	84.9	85.0	85.1	85.2	85.3	85.4
2.	79.7	80.0	80.2	80.4	80.6	80.8	81.0	81.2	81.4
3.	74.6	75.0	75.3	75.6	75.9	76.2	76.5	76.7	77.0
4.	69.7	70.1	70.5	71.0	71.4	71.7	72.1	72.5	72.8
5.	64.9	65.5	66.0	66.5	67.0	67.4	67.9	68.3	68.7
6.	60.4	61.1	61.7	62.2	62.8	63.3	63.8	64.2	64.7
7.	56.2	56.9	57.5	58.2	58.7	59.3	59.9	60.4	60.9
8.	52.3	53.0	53.7	54.3	55.0	55.6	56.1	56.7	57.3
9.	48.5	49.3	50.0	50.7	51.4	52.0	52.6	53.2	53.8
10.	45.1	45.8	46.6	47.3	48.0	48.6	49.3	49.9	50.5
11.	41.8	42.6	43.4	44.1	44.8	45.5	46.1	46.8	47.4
12.	38.8	39.6	40.4	41.1	41.8	42.5	43.2	43.8	44.5
13.	36.0	36.8	37.5	38.3	39.0	39.7	40.4	41.0	41.6
14.	33.4	34.2	34.9	35.6	36.3	37.0	37.7	38.4	39.0
15.	30.9	31.7	32.4	33.1	33.9	34.5	35.2	35.9	36.5
16.	28.6	29.3	30.1	30.8	31.5	32.2	32.8	33.5	34.1
17.	26.4	27.2	27.9	28.6	29.3	30.0	30.6	31.3	31.9
18.	24.4	25.1	25.8	26.5	27.2	27.8	28.5	29.1	29.7
19.	22.4	23.2	23.8	24.5	25.2	25.8	26.5	27.1	27.7
20.	20.6	21.3	22.0	22.6	23.3	23.9	24.6	25.2	25.8
21.	18.8	19.5	20.2	20.8	21.5	22.1	22.7	23.3	23.9
22.	17.2	17.9	18.5	19.1	19.8	20.4	21.0	21.6	22.2
23.	15.6	16.3	16.9	17.5	18.1	18.7	19.3	19.9	20.5
24.	14.1	14.7	15.4	16.0	16.6	17.2	17.7	18.3	18.9
25.	12.7	13.3	13.9	14.5	15.1	15.6	16.2	16.8	17.3
26.	11.3	11.9	12.5	13.0	13.6	14.2	14.7	15.3	15.8
27.	10.0	10.5	11.1	11.7	12.2	12.8	13.3	13.8	14.4
28.	8.7	9.2	9.8	10.3	10.9	11.4	11.9	12.5	13.0
29.	7.4	8.0	8.5	9.1	9.6	10.1	10.6	11.1	11.6
30.	6.2	6.8	7.3	7.8	8.4	8.9	9.4	9.9	10.3
31.	5.1	5.6	6.1	6.6	7.1	7.6	8.1	8.6	9.1
32.	4.0	4.5	5.0	5.5	6.0	6.5	6.9	7.4	7.9
33.	2.9	3.4	3.9	4.3	4.8	5.3	5.8	6.2	6.7
34.	1.8	2.3	2.8	3.2	3.7	4.2	4.6	5.1	5.5
35.	.8	1.3	1.7	2.2	2.6	3.1	3.5	4.0	4.4
36.	*	.2	.7	1.1	1.6	2.0	2.5	2.9	3.3

TABLE 7

ZERO DEGREE ELEVATION TO GREAT CIRCLE ARC LENGTH CONVERSION

Height (Naut. Mi.)	Arc Length
100	13. 6
125	15. 2
150	16. 6
175	17. 9
200	19. 1
225	20. 2
250	21. 2
275	27. 2
300	23. 1
325	24. 0
350	24. 8
375	25. 6
400	26. 4
425	27. 1
450	27. 8
475	28. 5
500	29. 2
525	29. 8
550	30. 4
575	31. 0
600	31. 6
625	32. 2
650	32. 7
675	33. 3
700	33. 8
725	34. 3
750	34. 8
775	35. 3
800	35. 8
825	36. 2
850	36. 7
875	37. 1
900	37. 6

The transparent overlay containing the nominal sub-point track is rotated until the sub-point track is tangent to the 0°elevation circle east of the APT station. A hatch mark is then placed at the intersection of the sub-point track with the equatorial latitude circle. The transparent overlay is again rotated until the sub-point track is tangent to the 0° elevation circle west of the APT station. As before, a hatch mark is placed at the intersection of the sub-point track with the equatorial latitude circle. Any orbit whose ascending node occurs at a longitude between the two hatch marks on the equator can be tracked by the APT ground station antenna.

An azimuth-elevation diagram is a function of only two quantities: satellite height and the geographic latitude of the tracking antenna. Therefore, if we assume a constant satellite height (circular orbit) all azimuth-elevation diagrams will be identical for all ground stations located at the same latitude, regardless of hemisphere.

Theoretical tracking range limits referenced to the equator may be indicated on the tracking board by a strip of colored tape.

4.4.2 Empirical

In all probability, the tracking antenna will not receive a usable signal from the satellite at zero degrees elevation. Local topography and electronic interference will tend to increase the minimum elevation at which a usable signal can be received. Furthermore, it is probable that the minimum elevation for usable signal strength will not be constant for all azimuths.

The minimum elevation angle will have to be determined locally from experience. During the initial tracking exercises following launch, one may assume that the minimum usable elevation angle is about 5°. The antenna beamwidth is 40° so that small elevation angle errors (or azimuth errors) will permit signal acquisition sufficient to track the satellite. Small timing errors may be evidenced during early post-launch tracking, but these time errors will be reduced as experience and refinement occurs.

After the minimum usable elevation angles have been locally established, a refined tracking range limit may be established by the process outlined in Section 4.4.1. In place of using 0° elevation circles to define the equatorial longitude interval within which orbits can be tracked, the empirically determined minimum elevation angles will be used.

4.5 Derivation of Tracking Data

We shall assume, for the present, that we have obtained a sub-point track from the daily message and it is plotted on the transparent overlay. In addition, we have plotted hatch marks on the sub-point track which correspond to two minute markers referenced from the equator. We also have (from the daily message) the longitude interval, at the equator, of successive northbound equator crossings. These successive ascending nodes are also plotted (as arrows) on the equatorial latitude circle.

The following are a succession of steps which can be followed to determine which orbits can be locally acquired and to derive tracking data points:

a) Set ascending node of orbital track on the transparent overlay to the longitude of the ascending node given for the sample orbit in the daily message. Thus, the Nth orbit on the overlay now assumes the orbit number of the sample orbit in the daily message.

b) Note which arrows on the equatorial latitude circle fall within the tracking limits which have been established from Section 4.4.2. Add the orbit number of the sample orbit to the value shown at each successive ascending node. This step provides the operator with the number of orbits which can be tracked and the "orbit number" of each of the orbits which he can track.

c) The daily message provides the longitude and time interval between successive ascending nodes. Thus, the operator has the option of determining specific ascending node data (longitude and time) by two methods: incrementing successive longitudes and times to the sample orbit, or interpolating for longitude and time from every fourth ascending node given in the daily message.

d) Rotate the transparent overlay until the sub-point track intersects the ascending node of the first orbit which can be acquired locally. Read (interpolate) the times on the sub-point track, in minutes referenced to ascending node, at the two intersections of the sub-point track with the 0° elevation circle (or minimum elevation circle after it has been empirically determined). Convert the time referenced to ascending node to GMT by adding the time of ascending node (of the orbit being tracked) to the time read on the sub-point track. In the southern hemisphere, the time read on the sub-point track is subtracted from the ascending node time.

This step provides the operator with the approximate antenna elevation and time at which the satellite signal will first be acquired and the antenna elevation and time at which the satellite signal will be lost.

To determine the azimuth at signal acquisition and signal loss, one simply reads the values of the azimuth (on the azimuth elevation diagram) at the two points of intersection of the sub-point track, elevation angle and azimuth.

e) Antenna azimuth and elevation data points for tracking may then be obtained at convenient time intervals (approximately 1 minute) along the sub-point track which falls within the tracking limits of the local station.

f) For convenience, tracking data may be entered in a data sheet as shown in Table 8.

4.6 Example

Assume that an APT acquisition site exists in Costa Rica at 10 degrees north latitude and 84 degrees west longitude. Information from the daily message indicates that the ascending node for orbit 1421 is 75 degrees west longitude. Time of ascending node is 14 hr 00 min 00 sec (Z). Satellite height within the acquisition range is 450 nautical miles (834 kilometers).

The sub-point track on the tracking board overlay is rotated until the ascending node appears at 75 degrees west longitude. Observe that the acquisition range for this APT site extends into the southern hemisphere. Data points on the sub-point track which are labelled with negative two minute intervals from the equator are actually on orbit number 1420, not orbit number 1421. As the satellite crosses the equator northbound, the orbit number becomes 1421.

An APT tracking worksheet should be filled in (Table 9). Time, elevation and azimuth at signal acquisition and signal fade are the first points to be determined. Zero elevation for a satellite height of 450 nautical miles corresponds to 27.8 degrees of great circle arc length. At 27.8 degrees arc length the satellite sub-points are at azimuths (from the APT site) of 154 degrees (signal acquisition) at -4.2 minutes and 359 (signal fade) degrees at +11 minutes.

TABLE 8

APT TRACKING WORKSHEET

SIGNAL ACQUISITION:

TIME: ____________

ELEV: ____________

AZIMUTH: ____________

ORBIT NO: ____________

DATE: ____________

TIME ASC.NODE REF	TIME (Z)	GREAT CIRCLE DISTANCE	ELEVATION	AZIMUTH	RATES		PICTURE TIME	
					ELEV.	AZIMUTH		

REMARKS:

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TABLE 9

APT TRACKING WORKSHEET

(Sample)

SIGNAL ACQUISITION:
TIME: ____________
ELEV: ____________
AZIMUTH: ____________

ORBIT NO: 1420-21
DATE: ____________

TIME ASC.NODE REF	TIME (Z)	GREAT CIRCLE DISTANCE	ELEVATION	AZIMUTH	Per Minute RATES ELEV.	AZIMUTH	PICTURE TIME	
-4.2	13 55 12	27.8	0.0	154	+4.0	-5.0		Min Elev.
-4	13 56 00	27.0	0.8	163	+3.7	-1.0		
-3	13 57 00	23.7	4.5	162	+4.7	-4.0		
-2	13 58 00	20.0	9.2	148	+5.5	-5.0		
-1	13 59 00	16.5	14.7	143	+7.2	-6.0		
0	14 00 00	13.0	21.9	137	+8.2	-10.0		
+1	14 01 00	10.0	30.1	127	+8.6	-13.0		
+2	14 02 00	7.7	38.7	114	+6.0	-19.0		
+3	14 03 00	6.4	44.7	85	+1.0	-26.0		
+3.5	14 03 30	6.3	45.2	72	-4.8	-34.0		Max. Elev
+4	14 04 00	6.8	42.8	55	-8.4	-22.0		
+5	14 05 00	8.8	34.4	33	-9.2	-15.0		
+6	14 06 00	11.5	25.2	18	-7.7	-7.0		
+7	14 07 00	15.0	17.5	11	-5.4	-5.0		
+8	14 08 00	18.1	12.1	6	-4.3	-3.0		
+9	14 09 00	21.0	7.8	3	-4.6	-2.0		
+10	14 10 00	24.8	3.2	1	-3.2	-1.0		
+11	14 11 00	27.8	0.0	359	STOP	STOP		Min. Elev.

REMARKS:
Do Not Exceed: 35°/min Elevation
350°/min Azimuth
Asc. Node {75 W Long, 14 00 00Z}
Ht. 450 N. Mi.
SIGNED: L. A.

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The third data point should be determined at the maximum elevation angle of the antenna during this satellite interrogation. The maximum elevation angle of the antenna occurs when the projected satellite sub-point track on the transparent overlay is nearest to the geographic location of the APT site (origin of red tracking diagram). This point occurs at +3. 5 minutes. Great circle distance is 6. 3 degrees (45. 2 degrees elevation) and azimuth is 72 degrees. The maximum elevation point is significant for two reasons: first, elevation rates set on the antenna tracking console will change from positive to negative rates; second, the maximum elevation and azimuth rates will be prevalent near maximum antenna elevation necessitating more frequent changes of tracking rates.

Intermediate tracking points may then be determined at one minute intervals referenced from/to the ascending node. Great circle arc length to elevation angle interpolations in time will usually be required.

Tracking rates in degrees per minute are the required inputs for the antenna tracking console. These values are obtained by simply taking successive differences of elevation and azimuth provided that the data points are at one minute intervals. If successive data points are not at one minute intervals it is necessary to normalize the rates to one minute time increments. Normalization will usually be required in four instances:

1) time of minimum elevation angle to the first whole minute, i. e. , -4. 2 to -4. 0 minutes.
2) whole minute before maximum elevation angle, i. e. , +3. 0 to +3. 5 minutes.
3) time of maximum elevation angle to the first following whole minute, i. e. , +3. 5 to +4. 0 minutes.
4) whole minute before time of minimum elevation (signal fade) angle.

A word of caution is required. The maximum elevation rate of the APT antenna is 35 degrees per minute. Maximum azimuth rate is 350 degrees per minute. Values in the RATES columns on the APT worksheet should never exceed these values.

Modification of the procedures outlined above will undoubtedly occur as tracking experience is gained. This may result in fewer data point determinations.

SECTION V
LOCATION OF PICTURE SUB-POINT

5.1 Introduction

The picture sub-point is simply the sub-point of the satellite at the instant that the camera shutter on the satellite opens, i.e., the time of picture taking. Two distinct procedures are necessary to determine the geographical location of the picture sub-point:

a) Orbit number during which the picture was taken.

b) Time (Z) of picture taking.

Significance of the location of the picture sub-point is that, under ideal conditions, the picture sub-point is also the principal point of the picture. Since the principal point is indicated on the picture by a fiducial marker, this permits the analyst to place the picture principal point directly on a scaled map on which the picture sub-point has been marked. Appropriate picture rotation about the picture sub-point will result in a geographically referenced image.

5.2 Orbit Number

The orbit number on which the picture was taken should be noted. In Section IV the method of determining orbit number was discussed with reference to tracking the satellite. Two important quantities should be noted about the orbit on which pictures were taken:

a) Ascending node longitude interval between the sample orbit on the daily message and the orbit on which the picture was taken.

b) Time (Z) of ascending node of orbit on which picture was taken.

Both of these quantities have been previously established for the tracking procedure.

5.3 Picture Time

The time (Z) at which the picture was taken is locally determined during the tracking procedure. The occurrence of an audible tone during the tracking operation signifies the opening of the on-board camera shutter. The time (Z) of the occurrence of this tone must be noted.*

After the picture time (Z) has been established, it would be convenient to reference this picture time to the time of ascending node of the orbit. This is accomplished by subtracting ascending node time from picture time when the picture was taken in the northern hemisphere. Pictures taken in the southern hemisphere require that the picture time be subtracted from the ascending node time of the following orbit. Picture time is now in the form of "x" minutes after (or before) the ascending node of a specific orbit.

5.4 Picture Sub-Point Location

At this point we have information about picture time and the orbit on which the picture occurred. It now remains to transform this information in terms of picture sub-point (principal point) location on a map.

5.4.1 Regional Map

A series of special transparent Regional Maps have been prepared for use with the APT ground operation. Each APT ground station will receive a map covering an area of the earth which might be visible in pictures taken in its vicinity. The regional map contains latitude-longitude lines for every fifth degree; one degree latitude intersections are shown by dots.

Regional Maps have been prepared for five degree latitude increments from the equator to 85 degrees. Each APT ground station will be provided with an appropriate Regional Map. Longitude lines on the map are not labelled. At the APT station the consumer will fix the ground station location at the center of the map. Appropriate longitudes values, in five degree increments, may then be assigned to the longitude lines on the Regional Map.

The Regional Maps are drawn to the same scale as the area viewed in the pictures. Obviously, the picture scale is a function of satellite (camera) height. Height (or scale) compensation is accomplished by changing the map

*In actual practice a small constant time interval, to be specified, will be added to the time of occurrence of the audible tone.

scale. Five maps are provided (at 50 km intervals) each corresponding to a different satellite height. The appropriate map is chosen by observing the satellite height (at picture time) from the daily message.

Satellite heading lines should be plotted on the Regional Maps at any convenient longitude interval. Data for plotting the heading lines are presented in tabular form in a supplemental kit.

The Regional Map will be used to "spot" the principal point (picture sub-point) of the picture. The facsimile picture will then be oriented under the transparent map for geographic referencing purposes and for display.

5.4.2 Picture Sub-Point Calculations

Knowing the picture sub-point time in minutes and decimals referenced from ascending node, it is now necessary to find the latitude and longitude at this time. The following steps describe a procedure for determining the latitude and longitude of the sub-point associated with the picture time.

a) From the sample orbit in the daily message one locates the latitude and longitude associated with the two minute interval data points adjacent to the picture time. One then adds to each data point (longitude) the longitude interval between the ascending node of the sample orbit and the ascending node of the orbit on which the picture was taken. The longitude addition is to be made from the sample orbit towards the westward direction.

b) Plot both incremented data points on the Regional Map at the incremented longitudes but at the original latitudes. Now, each data point has been translated westward, at its respective latitude, by an amount equal to the longitude difference between the sample orbit and the "picture" orbit.

c) To spot the picture sub-point on the Regional Map, it is necessary to interpolate linearly in time between the two data points. A variable scale would assist the interpolation process.

Steps "a" through "c" are repeated for every picture sub-point. For all picture sub-points on the same orbit, the longitudinal translation will be identical.

5.4.3 Picture Sub-Point Approximations

The APT Tracking board may be used as a back-up technique for locating picture sub-points. This method is not as accurate as that described above, but may be useful under certain circumstances when supporting data are not available.

The orbital track on the transparent overlay is placed on the longitude of the ascending node of the orbit on which the picture was taken. Picture sub-point time is then interpolated between the two adjacent hatch marks (representing two minute intervals from ascending node) on the orbital track. Latitude and longitude of the interpolated picture sub-point are noted and are then transferred to the Regional Map.

5.4.4 Sectional Maps

Sectional Maps are merely the central portion of the Regional Maps. The Sectional Maps will be used primarily by personnel operating in mobil vans which were designed to contain APT readout facilities.

The major advantage provided by use of Sectional Maps is the smaller physical size of those maps which result in easier handling in cramped quarters. Sectional Maps are intended for gridding one picture at a time. However, sufficient map area (exceeding picture orea) exists on these maps to permit three successive pictures to be gridded by two Regional Maps. This is a desirable feature since, at some time, the consumer may wish to prepare a mosaic.

All data handling procedures discussed with reference to the Regional Maps apply to the Sectional Maps.

SECTION VI
GEOGRAPHIC REFERENCING

6.1 General

All geographic referencing techniques commence with the spotting of the theoretical picture principal point on the Regional Map as discussed in Section V. After the picture is mated to the Regional Map all picture elements are located since the map is constructed to the picture scale.

A succession of pictures may be attached to the underside of the map for simultaneous (mosaic) display. The mosaic may be filed for future reference. It is suggested that the latitude-longitude lines be transferred to the picture to retain geographic references. This may be accomplished by placing the mosaic over the Regional Map (on a light table) and copying the latitude-longitude lines directly on the mosaic with a grease pencil.

6.2 Heading Line

The satellite heading line is the instantaneous projection of a satellite orbit on the earth. Therefore, the heading line is a sub-point track on a non-rotating earth.

Perfect Nimbus stabilization would theoretically permit the drawing of a heading line on the picture parallel to the left and right edges of the picture, through the indicated principal point. The calculated principal point on the Regional Map is then superimposed on the picture principal point and the Map is rotated to make the map and picture heading lines parallel. It should be remembered that the bottom (south) of the picture is the first to be scanned on the facsimile machine.

Any departure from perfect stabilization of Nimbus or any picture timing error will result in geographic referencing errors. Small attitude or timing errors produce relatively insignificant referencing errors.

The consumer will be provided an estimate of only one of the three possible attitude deviations in the daily message. A yaw correction angle will be stated. Effectively, the yaw correction angle denotes the amount of rotation (about the superimposed map and picture principal points) from the heading direction on the Regional Map to the projected heading line drawn on the televised picture.

Pitch and roll data will not be directly available to the APT co· umer.

6.3 Overlapping Pictures

An alternate geographic referencing technique may be used when portions of of two successive pictures view the same area. The northern part of a picture taken at time t should be examined along with the southern part of the succeeding picture (t + 208 sec.) to determine whether any common features can be found in the two pictures.

A recommended procedure for using the overlapping technique is as follows;

a) Place each picture principal point over its associated principal point which has been spotted on the Regional Map.
b) Rotate each picture about its principal point until a best fit between match points on each picture is achieved.

Following the procedure it is recommended that the apparent yaw angle between the heading direction on the map and that on the picture be measured and recorded. A consistant pattern may become evident to assist in subsequent geographic referencing activities.

6.4 Geography

Many large scale and a few small scale geographic features of the earth will be visible in the Nimbus pictures. Almost all large scale land-water interfaces can be clearly recognized in the absence of clouds. On a smaller scale it is often possible to observe narrow rivers (greater than 1/2 mile width) and small lakes.

If one or more recognizable features appear in the picture, these picture elements can be placed under the proper latitude-longitude of the Regional Map. The remainder of the picture is then automatically fixed.

A good atlas should be present at each APT site and personnel should become familiar with local topography.

6.5 Climatology

A cloud climatology within the APT acquisition region may also prove useful. In many instances clouds (or other atmospheric particulate) may consistently appear at or near certain topological features. The location of these clouds should be determined. If these clouds appear in the picture a location "fix" can be made as described in Section 6.4.

SECTION VII
PROCEDURE ROUTINE: REVIEW

7.1 Pre-Acquisition Preparation

a) Obtain daily message.

b) Position the sub-point track of the reference orbit on the Tracking Board according to the time and longitude of the ascending node.

c) Determine those orbits whose sub-point track lies within the acquisition range.

d) Rotate the orbit track to the ascending node of those orbits which can be acquired.

e) Read the time, azimuth and great circle arc length at initial and final tracking limits. Convert great circle arc length to elevation angle using the tables provided. Satellite height is required for this conversion and it may be approximated from data given in the daily message.

f) Determine azimuth and elevation angles at convenient time intervals (usually 1 minute) within the acquisition range.

g) Determine azimuth and elevation rates required for setting dials on console.

h) Steps "a" through "g" should be repeated for all orbits which can be acquired during the day.

7.2 Acquisition

a) At specified time begin the tracking routine.

b) Note the picture time during tracking.

7.3 Post-Acquisition

a) Determine picture sub-point and place it on the Regional Map.

b) Place picture center on picture sub-point plotted on the Regional Map.

c) Rotate picture about the principal point until it is aligned with landmarks. If landmarks do not appear in the picture, alignment must be made with the heading line on the Regional Map.

APPENDIX A
TIROS ATTITUDE

A. 1 General

TIROS is a spin stabilized satellite. The vehicle rotates about its spin axis which can be considered as fixed in space for sho· ·eriods of time. The APT camera is mounted parallel to the spin axis and for all practical purposes the optical axis of the camera and the spin axis of the satellite can be considered coincident.

TIROS APT cameras will not view the earth at all times. During about one half of the orbital period, some part of the earth will be viewed by the camera. Useful pictures can be obtained from less than half of the orbital segment during which the lens is pointed towards the earth.

A. 2 Attitude System

Attitude of the TIROS camera (spin) axis can be described in an orbital coordinate system. First, we assume that the spatial location of the satellite is known (from daily message data) for any instant of time. The attitude problem deals only with the orientation of the camera axis at a given instant of time. Two parameters can be used to define the orientation of the camera axis. They are defined by:

a) n_o = minimum nadir angle during an orbital period
b) t_o = time at which n_o occurs

The minimum nadir angle may be defined as the smallest angle made between the orbital plane and the camera spin axis during any one orbital period. The principal line has the property of being very nearly perpendicular to the sub-point track at the time of minimum nadir angle.

The diagram in Figure A-1 relates the nadir angle during half an orbital period to the time interval between picture time and t_o for a given n_o. Figure A-2 relates the azimuth of the principal line at picture time with n_o and t_o. Both n_o and t_o are provided in the daily message.

FIG. A.1

ATTITUDE DIAGRAM

NADIR ANGLE

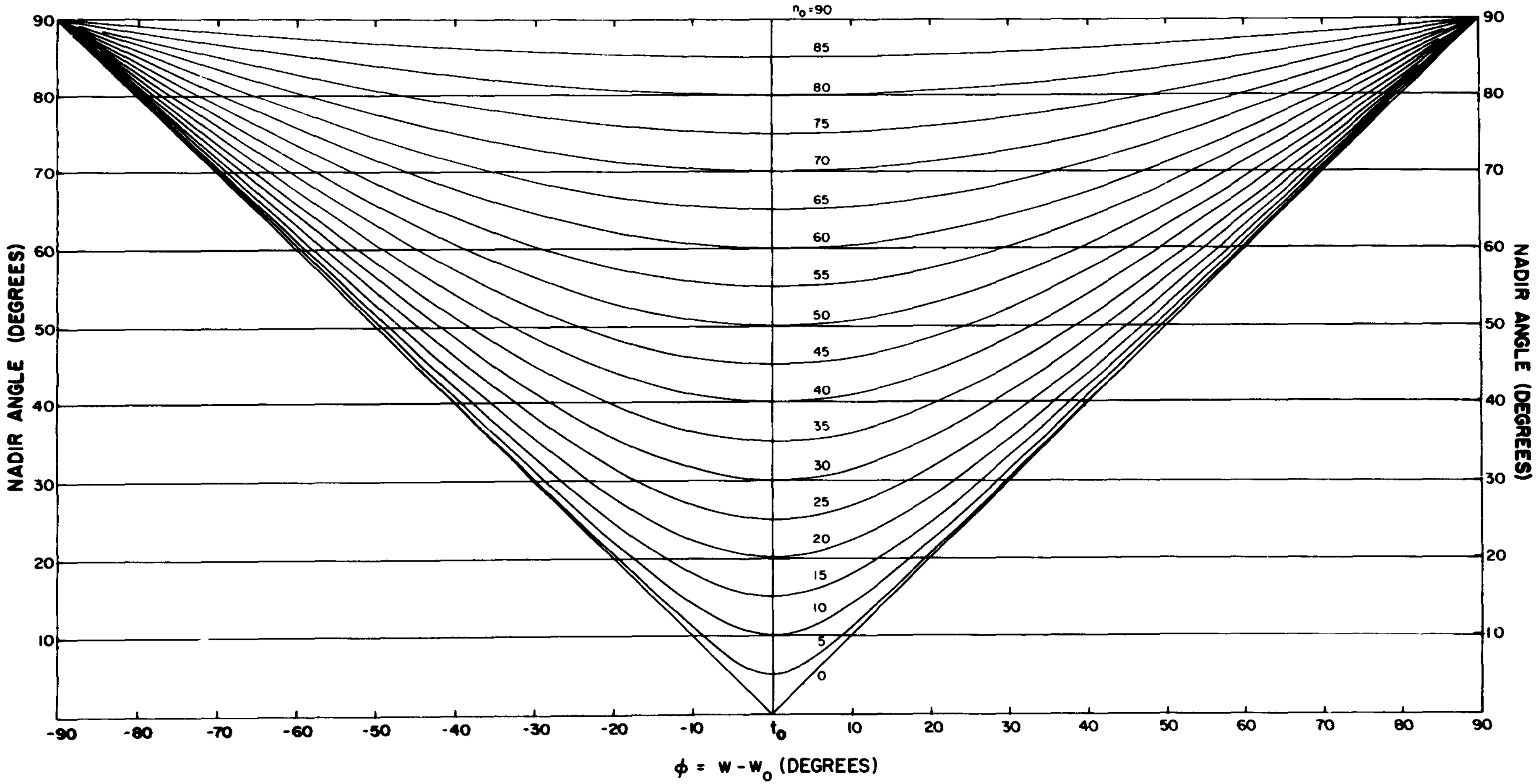
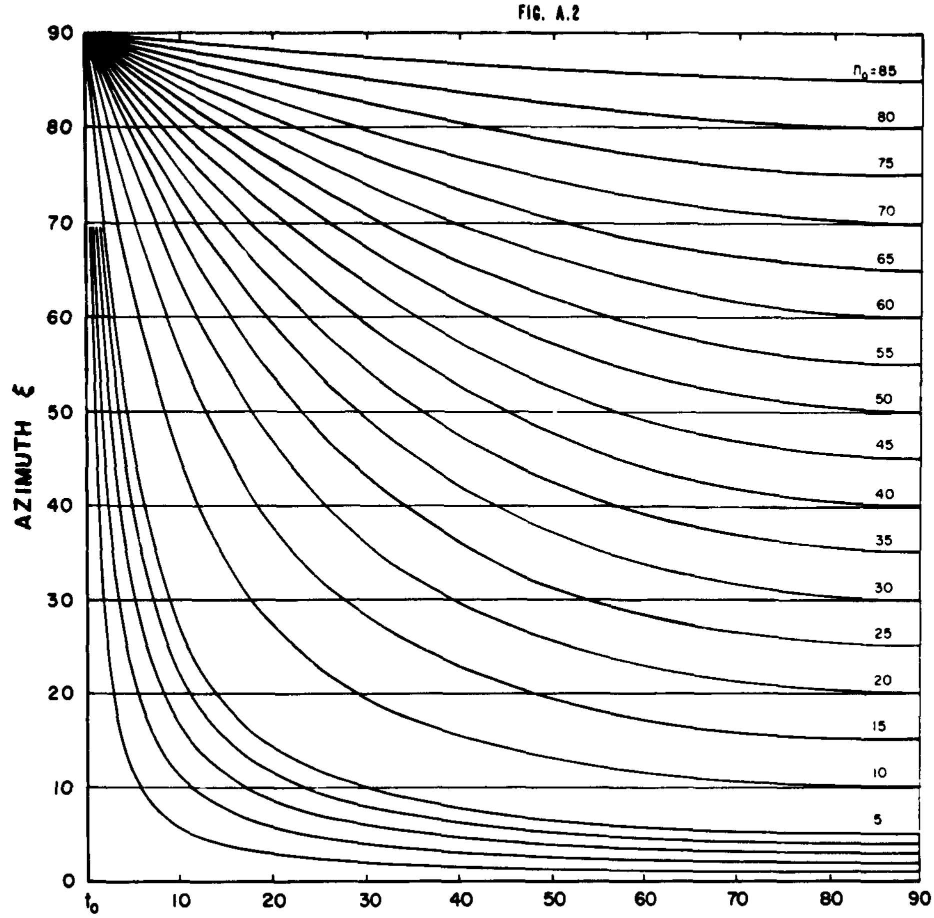
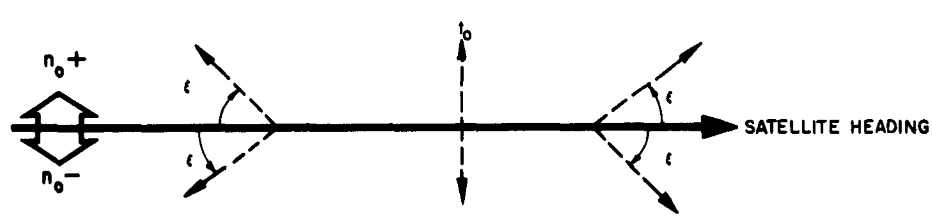


FIG. A.2



ATTITUDE DIAGRAM
AZIMUTH



A series of time-interval scales are provided (in a separate kit) for use with both attitude nomograms (Figures A-1 and A-2). These time scales (Figure A-3) are used to convert satellite anomaly ($w-w_o$) to the operationally convenient time scale. Each time scale is computed for a circular orbit with varying orbital periods. The user will select the appropriate time scale by reading the orbital period as stated in the daily message. The value of the orbital period will not change significantly over a period of months so that a single time scale is used for the lifetime of the satellite.

Hatch marks on the time scale represent one minute intervals of time. The scale is fixed over the abscissa of each diagram with t_o being the starting point. Note that the number of minutes represented on the time scale between t_o and 90^o is about one quarter of the orbital period. On the Nadir Angle Diagram two identical time scales are fixed to the abscissa, each one starting at t_o and heading in opposite directions. The entire time span covered on the Nadir Angle Diagram from minus 90^o through t_o to plus 90^o is one half an orbital period.

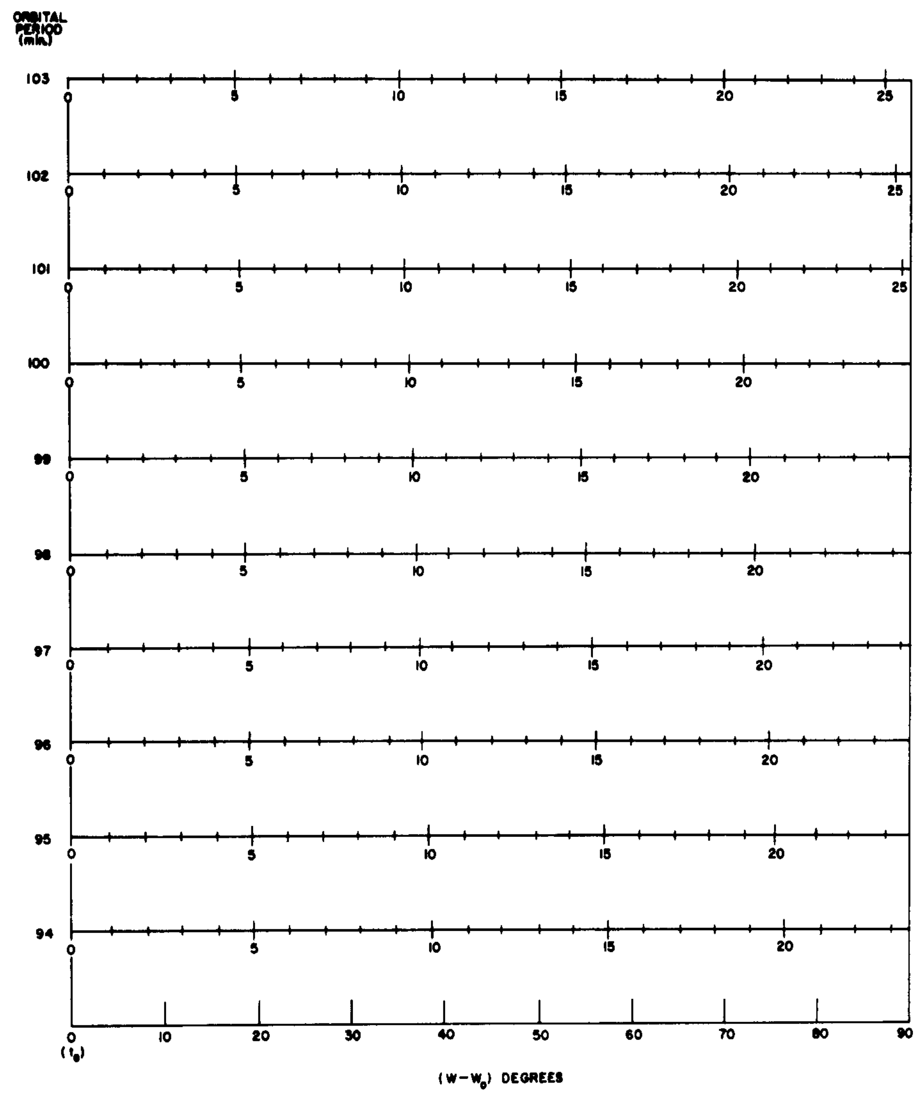
A. 3 Procedures

Plot the sub-point track of the satellite in the vicinity of the acquisition range of the local antenna on the Oblique Equidistant Cylindrical (OEC) map projection. Two minute interval data points are obtained from the daily message. Longitude values of the sub-point may be determined as previously described (see Section 5. 4. 2) if the orbit track in question is not the reference orbit given in the daily message.

During satellite interrogation determine the picture time. Convert picture time to minutes after ascending node time and plot this point on the sub-point track. A time interpolation between two minute interval data points will usually be necessary. Obtain the value of n_o and t_o from the daily message. Determine the time difference between picture time and t_o.

Using the diagram in Figure A-1 read the time difference between picture time and t_o on the abscissa time interval scale. Then project a vertical from the abscissa to the curve representing the value of n_o as found from the daily message. Read the value of the nadir angle (n) on the ordinate.

FIG. A.3
TIME SCALES FOR ATTITUDE NOMOGRAMS
(CIRCULAR ORBIT, ONE QUADRANT)



The aximuth of the principal line can be determined from the diagram in Figure A-2. As before, the time difference between t_o and picture time is located on the abscissa and a vertical is projected to the appropriate n_o curve. Azimuth (ξ) is then read on the ordinate. The azimuth angle is measured from the satellite heading line (or to a good approximation from the subpoint track). A principal line is then drawn from the picture subpoint at the angle ξ .

On the lower portion of Figure A-2, the method of "directing" the principal line is shown. If n_o is positive, the principal line is directed toward the left of the heading line (or subpoint track) when facing the direction in which the satellite is moving. For a negative n_o, the directed principal line is towards the right.

The azimuth angle (ξ) is measured as shown in the diagram. Note that if the picture subpoint occurs after t_o, the azimuth is measured from the "forward" heading line. If the picture subpoint occurs before t_o, the azimuth is measured from the "rear" of the heading line.

At this point the OEC Map projection contains the directed principal line (or lines). The next step is to locate the principal point of the picture on the principal line on the map. Table A-1 indicates the distance (in degrees of equatorial latitude on OEC map) between the subpoint and principal point as a function of satellite height and nadir angle.

A. 4 Perspective Rectification

A. 4. 1 Introduction

The meteorological information to be obtained in the TIROS pictures can be put to operational use only if the locations of the observed phenomena can be established reasonably well. Essentially, then the problem becomes one of finding corresponding points in the pictures and on a map. The correspondence should be presented in a fashion that makes the location of features in the picture readily obvious.

The method established here for the location of features in the pictures is based upon the "Canadian Grid" system of photogrammetry. The perspective grid is a network of lines constructed for an oblique photograph, the lines representing corresponding lines of an imaginary rectangular grid on the

TABLE A-1

SUB-POINT TO PRINCIPAL POINT DISTANCE (DEGREES OF EQUATORIAL LATITUDE)

NADIR ANGLE	HEIGHT (Nautical Miles)								
	400	425	450	475	500	525	550	575	600
	HEIGHT RANGE (Kilometers)								
	718 to 764	765 to 810	811 to 856	857 to 903	904 to 949	950 to 995	996 to 1042	1043 to 1088	1089 to 1134
0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2	.2	.2	.2	.2	.2	.3	.3	.3	.3
4	.4	.4	.5	.5	.5	.6	.6	.6	.6
6	.7	.7	.7	.8	.8	.9	.9	1.0	1.0
8	.9	.9	1.0	1.1	1.1	1.2	1.2	1.3	1.4
10	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7
12	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2.0	2.1
14	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.5
16	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8
18	2.1	2.3	2.4	2.5	2.7	2.8	3.0	3.1	3.2
20	2.4	2.5	2.7	2.9	3.0	3.2	3.3	3.5	3.6
22	2.7	2.8	3.0	3.2	3.4	3.5	3.7	3.9	4.0
24	3.0	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5
26	3.2	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9
28	3.6	3.8	4.0	4.2	4.5	4.7	4.9	5.2	5.4
30	3.9	4.1	4.4	4.6	4.9	5.1	5.4	5.6	5.9
32	4.2	4.5	4.8	5.0	5.3	5.6	5.9	6.2	6.4
34	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0
36	5.0	5.3	5.6	5.9	6.3	6.6	6.9	7.3	7.6
38	5.4	5.7	6.1	6.4	6.8	7.2	7.5	7.9	8.3
40	5.8	6.2	6.6	7.0	7.4	7.8	8.2	8.6	9.0
42	6.3	6.7	7.1	7.5	8.0	8.4	8.9	9.3	9.7
44	6.8	7.3	7.7	8.2	8.7	9.1	9.6	10.1	10.6
46	7.4	7.9	8.4	8.9	9.4	10.0	10.5	11.0	11.6
48	8.0	8.6	9.1	9.7	10.3	10.9	11.5	12.1	12.7
50	8.7	9.3	10.0	10.6	11.3	11.9	12.6	13.3	14.1
52	9.5	10.2	11.0	11.7	12.4	13.2	14.0	14.8	15.7
54	10.5	11.3	12.1	13.0	13.9	14.8	15.7	16.7	17.8
56	11.7	12.6	13.6	14.6	15.7	16.8	18.0	19.3	20.7
58	13.1	14.3	15.5	16.8	18.2	19.7	21.5	23.7	26.8
60	15.1	16.6	18.3	20.2	22.6	26.4	--	--	--
64	18.2	20.7	24.7	--	--	--	--	--	--

ground. The perspective grid is superimposed on the picture while a corresponding rectangular (transfer) grid is superimposed in the proper location and orientation on a map. A one-to-one correspondence then exists between lines and intersections of lines in the picture and on the map. A typical perspective grid for TIROS is shown in Figure A-4. A corresponding rectangular transfer grid is shown in Figure A-5.

The starting point for the gridding system is taken as the principal point of the picture. The principal point of the picture is defined as the intersection of the camera axis with the image plane. A corresponding principal point in the object space exists at the intersection of the camera axis with the surface of the earth. This point corresponds more or less exactly with the intersection of the spin axis of the satellite with the surface of the earth. If prediction of satellite attitude is successful, the predicted position of the principal point on the earth's surface should be reasonably accurate. For the sake of further argument, the position of this point will be taken as accurately determined.

A. 4. 2 Perspective Grids

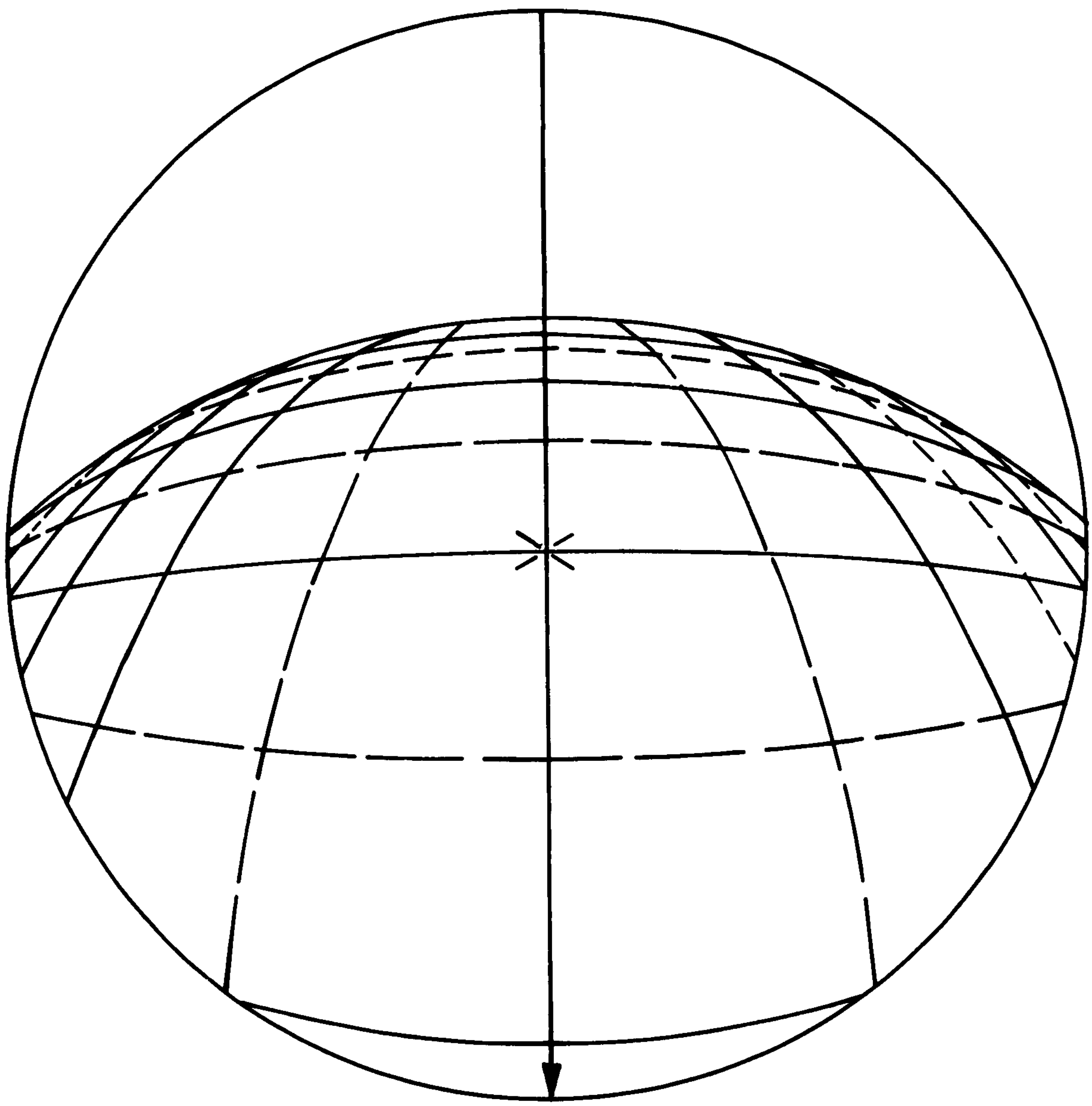
A library of perspective grids is provided for increments of satellite altitude and camera nadir angles. Each perspective grid displays the location of the principal point (marked "X") with the principal line drawn through it. The curvature of the horizon is also shown for those perspectives (attitudes) which permit the earth's horizon to be viewed by the camera.

Latitude and longitude curves on the grids are drawn for three degree intervals starting from the principal point.

An appropriate perspective grid (function of satellite height and nadir angle) is selected from the grid library. The principal point of the grid ("X") is made to coincide with the indicated principal point on the picture. Rotate the perspective grid about the principal point until the grid horizon makes a best-fit with the image horizon. The combined image of the perspective grid on the televised picture gives a gridded perspective view of the earth as it was seen by the satellite optics when the camera shutter was open. However, the perspective grid lines (at three degrees of latitude and longitude) must now be identified and transformed to a more conventional and useable map projection. This transformation is accomplished through the use of a transfer grid.

FIG. A.4

SAMPLE TIROS PERSPECTIVE GRID
METEOROLOGICAL SATELLITE



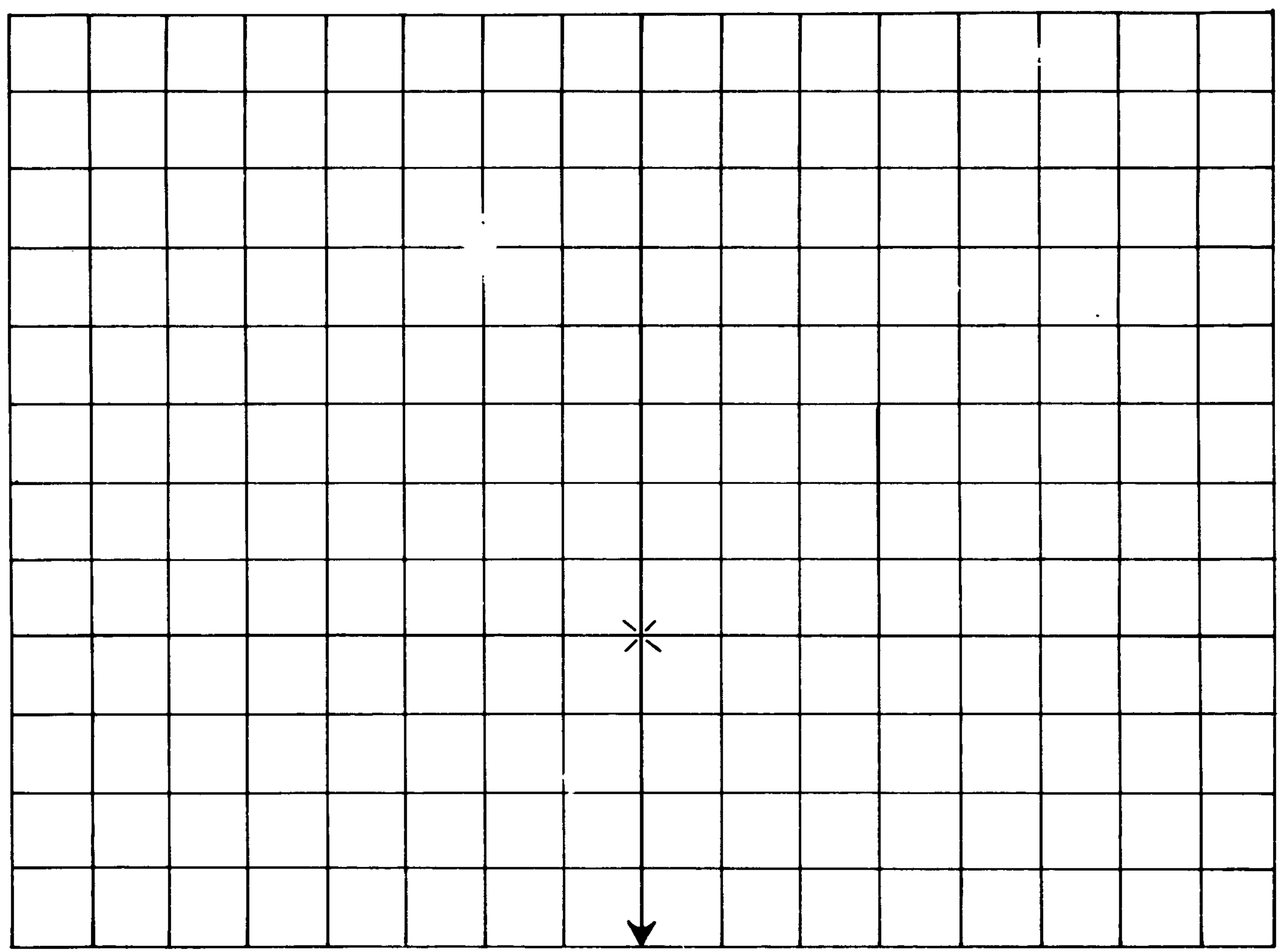


FIG. A.5
TRANSFER GRID
TIROS METEOROLOGICAL SATELLITE

A. 4. 3 Transfer Grid

A quadrilateral transfer grid of the appropriate scale is place on a map which is used as a location guide and transfer medium. The transfer grid is drawn to the scale of the map to be used. The principal point of the transfer grid is place on the map at its correct geographical location as determined from the satellite subpoint and axis orientation. The principal line of the transfer grid is oriented along the azimuth from the principal point toward the satellite subpoint. Then the transfer grid corresponds, point by point, with the perspective grid on the satellite picture. It is a relatively easy operation to transfer significant points on the picture to their corresponding points on the map or if desired to transfer latitude-longitude lines from the map to the picture.

A. 5 Pictures Without Horizons

A special problem in rectification of TIROS pictures exists when the earth's horizon does not appear in the picture. Under these circumstances, the user is hard pressed when he must align the perspective grid with the picture.

For the above case, a technique has been developed by ARACON Laboratories which will assist the user in aligning the perspective grid with the picture. The theoretical background of this rectification system will not be described here. Only the operational procedures will be outlined.

Two angles called "R" and "S" will be used to ascertain the principal line orientation in the picture.

From the daily message, the user can obtain the value of the "S" angle which will be reported at two minute intervals. Interpolation for "S" values between two minute data points is permissible.

The "S" angle (measured at the picture principal point) is the angle measured counterclockwise from a line directed from the picture principal point to the central right "T" shaped fiducial mark on the picture. The central right "T" shaped fiducial mark is located by holding the picture in front of the user so that the top part of the picture is in the direction in which the satellite is heading. The top part of the picture comes in last over the facsimile machine.

A line is then directed from the picture principal point at "S" degrees from the line to the "T" shaped fiducial. The directed line at "S" degrees represents the forward direction of the satellite heading line in the picture. The principal line in the picture will then be another directed line of R degrees measured from the forward heading line. The angle R is measured counterclockwise from the forward heading line. Figure A-6 shows the relations between the R and S angles on the picture.

It should be noted that the R angle has nearly the same value as the azimuth angle (ξ) for small nadir angles ($n<30$). Figure A-7 shows the relationship between R and ξ. As n increases, the difference between R and ξ increases; however, for $n > 30$ a portion of the horizon will appear in the picture and the use of R and S angles will not be required.

After the principal line is oriented on the picture, the rectification technique is reduced to the standard method outline in the previous section.

In the event that the daily message is not available, one may extrapolate S angles for identical times after ascending node. Running graphs of S angles should be maintained and continually updated (from daily messages) at the APT station. These graphs will be used for extrapolation of S values.

FIG. A.6

R AND S ANGLES IN PICTURE

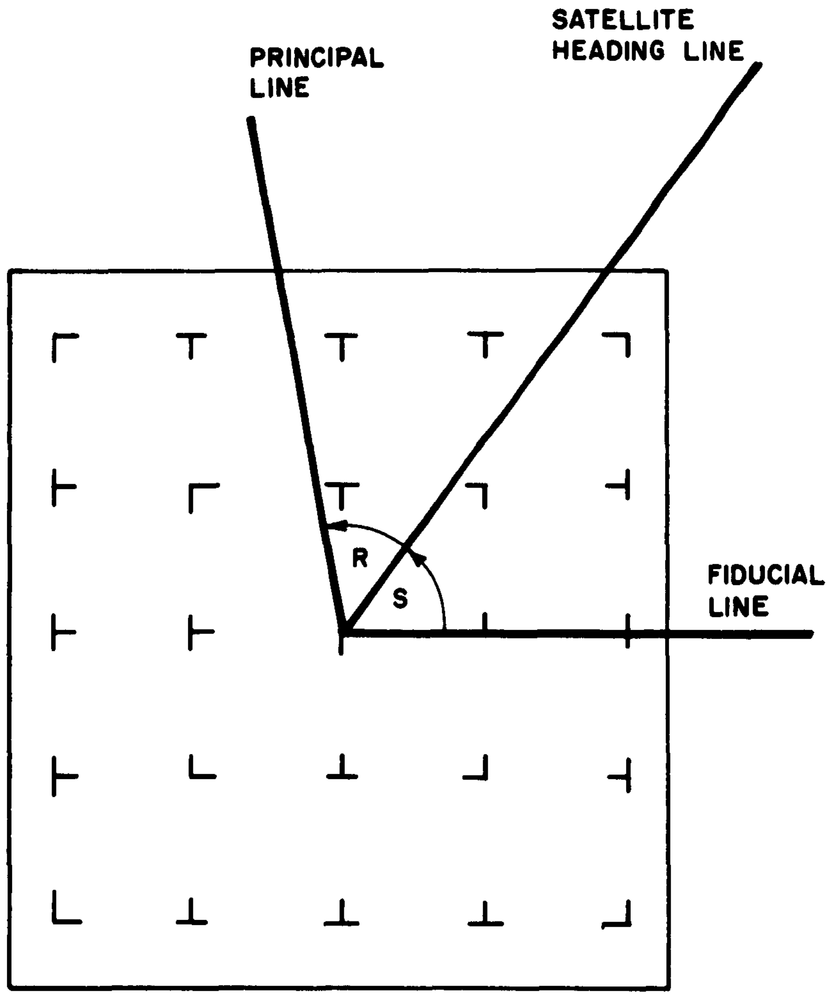
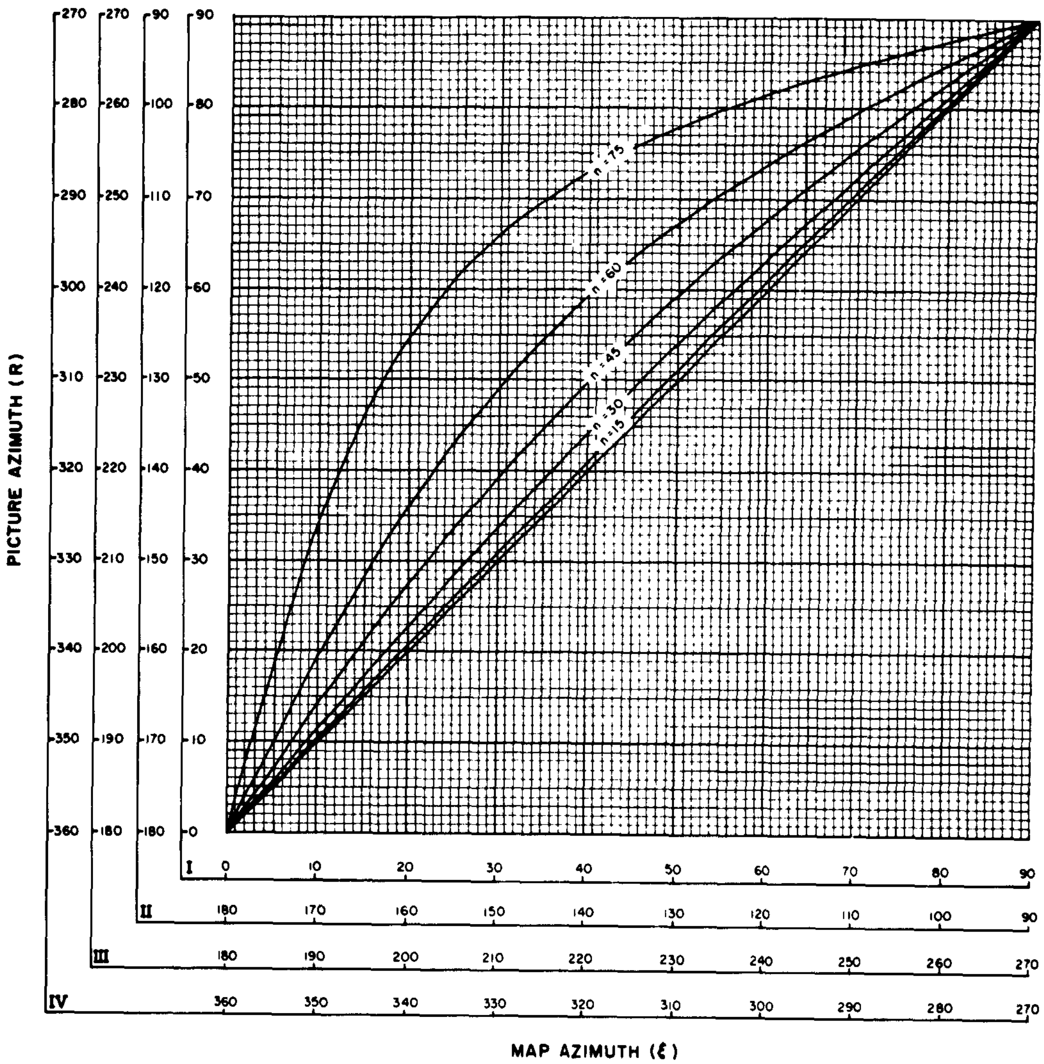
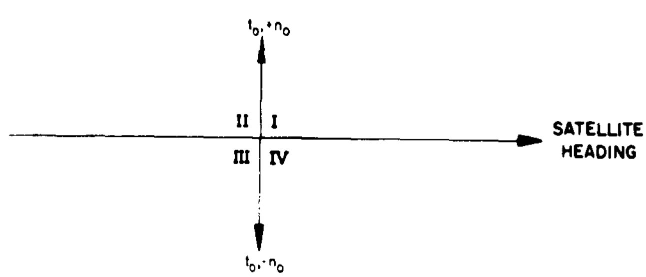


FIG. A.7

AZIMUTH TRANSFORM

R(ξ,n)





AF Cambridge Research Laboratories, Bedford, Mass. APT USERS' GUIDE SCIENTIFIC REPORT NO. 1 by Leon Goldshlak, June 1963 ARCRL-63-655 Unclassified report

The Nimbus Meteorological Satellite system will provide high altitude pictures of the earth's atmosphere. An Automatic Picture Taking (APT) subsystem will permit local picture readout at those sites which have appropriate terminal equipment. This guide is intended to serve as an

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1. Meteorological Satellites
2. Tracking
3. Rectification (Photography)

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introduction to data handling procedures at APT acquisition sites.

Specific subjects treated in the guide are: satellite tracking, picture rectification and geographic referencing. An appendix is included to assist personnel at the acquisition site with picture rectification problems of the experimental TIROS APT sub-system.

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